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The Bactericidal Effectiveness of Home Laundering Methods for Silk and Rayon

by

Evelyn H. Roberts

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SUMMARY

Washing, drying, and ironing tests made on rayon undershirts, inoculated with *Escherichia coli*, show that the present method of washing rayon or silk underwear eliminates less than one-half of the bacteria; drying indoors and outdoors in the sunshine eliminates approximately 99 per cent; ironing with a warm iron eliminates approximately 100 per cent. For prevention of skin infection caused by spore-bearing bacteria or fungi, ironing after outdoor or indoor drying is recommended. In case the garment cannot be ironed without damage to the fabric, the use of a germicidal or fungicidal rinse is advisable.

The Bactericidal Effectiveness of Home Laundering Methods for Silk and Rayon

By Evelyn H. Roberts*

INTRODUCTION

Laundering studies have dealt largely with the cleaning ability of washing methods or the effect of such methods on various textiles. Little has been done from a bacteriologic standpoint. The bactericidal effectiveness of present methods for laundering silk and rayon underwear was considered of interest and was made the subject of a research study under Purnell funds at the Washington Agricultural Experiment Station.

SURVEY OF THE LITERATURE

Certain general facts were derived from a survey of the literature. One was that very little scientific material was available on the subject. Another was that the number of micro-organisms present depended upon the length of time the garment was worn, the part of the body touched, and the fabric. A third, that pathogenic bacteria remained virulent on clothing for considerable periods of time.

Only two articles were found which dealt with actual laundering tests. Balderston, Wilson, and Harris (1), using inoculated cotton material pinned to garments and several laundering methods, obtained 99 per cent removal of bacteria by a method which included several hot baths (approximately 140°F.). Winegar (2) made a careful study of bacteria on worn cotton undershirts. Bacterial counts varied between 400,000 and 6,000,000 per square inch, depending upon the time worn. Washing these worn undershirts in ten baths of cold sterile water eliminated some but not all of the bacteria. Drying out of doors in shade or sunshine eliminated from 87 to 99 per cent of the bacteria.

Many experiments have been made on the effect of ultra violet rays in penetrating fabrics. The main conclusion is that the size of the interspace is the deciding factor. Latzke (3), starting with inoculated silk, wool, cotton, and linen, found that bacteria are held on the fabric by some physical force which defies washing action and that the ultra violet rays have greater germicidal action on organisms on cotton, linen, and silk than on those on wool of similar per cent interspace.

* The author acknowledges the assistance of Howard Lundy and Leonard Maxey and the cooperation of the staff of the Department of Bacteriology.

Washing agents, as soap and alkaline detergents thought to be germicides, have been investigated. A number of writers report that average concentrations of soap have no germicidal effect; certain strains of bacteria, however, are less resistant than others (4). High temperatures (140° F.), high alkalinity (pH 12), and five minutes of treatment are rated effective in milk pan sterilization. Alkaline detergents are also rated as effective, but only in combination with heat and when applied for ten minutes or more.

High temperatures alone have been considered effective for sterilization, but some bacteria can live in hot water and spore-bearing types are not destroyed by a single boiling. Most of the pathogenic bacteria are destroyed by temperatures of 140-158°F., maintained for 20 minutes (5). Hahn and Strauss (6) experimented with the effect of steam heated presses on inoculated garments, and concluded that ironing temperatures are effective against pathogenic bacteria.

The bactericidal efficiency of the power laundry has been questioned at times, but a number of articles indicated that present methods do produce the desired result by the use of high temperatures, several suds, many rinses, bleaching, and ironing. Johnson's (7) article on Sanitation and Power Laundry Methods summarized all known data on the subject.

Soaps and detergents containing bleaching material are much used in power laundery operation. German usage favors detergents affording free oxygen, which besides bleaching action has some germicidal effect.

Chlorine used as a bleach in power laundry processes is also effective as a germicide. Concentrations of chlorine in substances employed for bleaching are strong enough to destroy some but not all types of bacteria. Tonney (8) reported the death point of a number of different types of bacteria as so many parts per million of free chlorine in water. Because of the bleaching action of chlorine it should not be used on colored fabrics nor on silk or wool.

The bactericidal effectiveness of dry cleaning processes has been investigated by Jackson (9) and Connell and his co-workers (10). The former obtained 99.9 per cent removal of the bacteria placed on garments. The latter obtained effective removal of some bacteria but some types as *Anthrax Bacillus and staphylococci* persisted.

STATEMENT OF PROJECT

The stated object of this project was "To determine the effectiveness of home laundering methods for rayon and silk underwear from a bactericidal standpoint." It was hoped that the material gathered would indicate whether or not the practice of washing underwear in warm water and with neutral soap and indoor drying were satisfactory.

In defining terms used in the statement of the project, rayon was taken to mean any type of artificial silk made of cellulose, including viscose, Celanese, Chardonnet or Tubize, and cupraammonium or Bemberg. By silk was meant any washable, unsized silk fabric, as pongee or crepe de chine. It is well known that rayon and silk are fibers of vegetable and animal origin, respectively, and that they have decidedly different physical and chemical properties. Rayon thread is extruded through a metal orifice from a vat of chemically treated cellulose, whereas silk thread is twisted from the fibers reeled from the cocoon of the silk worm. Because of the nature and luster of the rayon fabrics, it is thought that rayon should be less easily soiled and more readily cleaned than silk. Both silk and rayon are damaged by alkalies and high temperatures; hence, laundering recommendations for both are the same.

Home laundering methods for these two fabrics include the following: the use of a mild or neutral white soap; cool or lukewarm water, i.e. temperatures of 90-100°F.; gentle rubbing for a few minutes; squeezing to remove water; drying; and ironing with a warm iron.

It is evident that with the suggested laundering methods, none of the conditions necessary for sterilization are met. Temperatures are too low, and neutral or slightly alkaline solutions have little or no bactericidal power. Garments of silk are often ironed with a warm iron, but it is only rarely that rayon undergarments or stockings are ironed so that the last possible means of sterilization is not employed. It was thus felt desirable to do some experimental work on the subject of the bactericidal efficiency of home laundering methods for these two fabrics and, if the present methods were not satisfactory, to devise some efficient procedure.

The Rayon Year Book of 1928-1929 (11) states, "The hygienic value of textile materials is more or less a new field which research is just opening up. It is well known that silk does not so readily support the growth of molds or bacteria as does cotton. Rayon, in this respect, has good sterile qualities. Its smoothness and slipperiness will not permit growth to accumulate easily if it is kept in a dry condition."

EXPERIMENTAL WORK

To determine the bactericidal efficiency of laundering, it was decided to test the effectiveness of removal of bacteria after the various stages of the process, as washing, drying, and ironing. Such tests involved certain preliminary experiments on materials, which are described in Series I, Materials. The removal of bacteria by the waters in which the garment was washed is discussed in Series II, Washing; the effectiveness of drying in Series III, Drying; and the same for ironing in Series IV, Ironing. Each one of these series has its own methods and results but the findings have new interpretations when compared with one another.

Series I, Materials

The materials used in laundering processes, as water, soap, and textile, have been studied before, but, since the purpose of this project was to determine the removal of bacteria from clothing, each of these materials had to be considered anew in relation to the bacteria selected for the inoculation of the cloth. The characteristics of this strain, preparation of the culture, inoculation, and method of sampling, plating, incubation, and counting will be described, as will tests on the effect of soap and temperature. Since it is known that every surface exposed to the air is covered with bacteria, experiments were made to estimate the usual number per square inch on the garment, that is, to obtain zero conditions, it being realized that absolute sterility of garment and hands was not feasible.

Escherichia Coli and Inoculation of Shirts. The *Escherichia coli,* commonly known as *Bacillus coli,* was selected for practically all tests since it was easily obtainable and among the hardiest of the non-pathogenic strains. *Staphylococcus aureus* was used in one experiment.

A culture of either strain was prepared as follows: one loopful of a broth culture was added to 51 cc. of a plain sterile broth and incubated for 24 hours. One cc. was then removed, diluted, plated, and incubated for a count. The remaining 50 cc. were poured over the cloth selected, lying in a sterile glass casserole (baked in an electric oven at 450°F. for one hour). After about ten minutes the cloth was subjected to laundering, and at the end of the process a sample was taken of the last water in which the cloth had been washed. Two thousand cc. of water in a one gallon aluminum vessel with cover and cover clamps had been sterilized by boiling for five to ten minutes.

Sampling. Sampling consisted of withdrawing ten cc. of the water with a sterile pipette (treated in an autoclave) and of placing the water in a sterile test tube. This was removed to the bacteriology laboratory where one cc. was removed by means of a sterile pipette and added to a test tube containing nine cc. of sterile water, a dilution of one to ten. The contents of this tube were mixed by shaking, then a one cc. sample was removed to a second water blank by means of another pipette, a dilution of one part in one hundred, and the process was repeated until the desired dilution was reached. One cc. of water from each test tube was placed in a sterile Petri dish. Agar, which had been melted and cooled to 108°F., was then poured over the plate and the plates placed in an incubating oven which was held at 98.6°F. At the end of 48 hours the plates were removed and a count of the colonies made. Assuming that each came from a single bacillus, the total number of colonies on the plate times the dilution gave the total number of bacteria in the first sample withdrawn. This number multiplied by the number of cc. of

water in the aluminum vessel gave the total number in the water in which the cloth had been washed. To figure the population or bacterial count per square inch of cloth, the total number was divided by the area of the cloth, one side only being considered.

The organism, *E. coli*, grows in a small white colony, by which characteristic a presumptive identification may be made. However, without a Gram stain and without sugar fermentation reactions, it is not known for certain that all such colonies are of this type. Hence an error may have been introduced by counting colonies as *E. coli* when they might have been something else. Another probable error in methods employed is the possible antagonism between *B. subtilis* and *E. coli*, the former entering during the washing process. Although *B. subtilis* did not appear on the plates to any great degree, it might have inhibited the growth of the *coli* organism. For all tests involving outdoor drying, it was necessary to use agar containing Gentian violet in a dilution of one to 100,000. This was done to inhibit the growth of Gram positive organisms such as *subtilis*.

Effect of Soap Suds and Temperature. Since water and soap solutions at low temperatures were to be employed in the experiments, it was desirable to know the effect of these agents on *E. coli*. Winslow and Falk (12) say that *E. coli* is particularly virile and remains viable for 24 hours in distilled water at room temperature. Schroeder and Southerland (13) reported actual tests in laundering involving a total processing time of almost an hour, a temperature of 93°F., and the use of woolen cloth inoculated with *E. coli*. No bacterial destruction took place at that temperature. Similar tests at 150°F. eliminated 50 per cent of the bacteria. Since temperatures less than 100°F. are recommended for silk and rayon, it was felt that these temperatures would have no effect on the bacteria selected, but a few laboratory tests were run to verify this point. Fifty cc. of a 24 hour culture of *E. coli* were added to two liters of a 0.25 per cent solution of White King soap powder. The temperature was slightly above room temperature (77-86°F.). The vessel was covered and shaken for 15 minutes, 10 cc. samples being removed at five-minute intervals. All of the samples showed approximately the same count as that of the original culture. A second test made at a higher temperature, 104°F., showed considerable diminution in the sample taken after 15 minutes of shaking. From these results it was decided to use solutions under 86°F. in all tests. The use of sterile water, neutral soap, and low temperatures were thus shown not to affect the chosen test organism, and any effect detectable would therefore be due to the mechanical agitation of washing, drying, or some other condition of the experiment.

Effect of Time. To determine the percentage removal of bacteria, four-minute washing and four-minute rinsing time was established.

To determine the population count after a drying process, a four-minute sampling period was also employed. This time period was selected after preliminary tests in which an inoculated garment was washed in two liters of sterile water for two minutes, a sample of water taken, and the washing continued for three, four, and five minutes, samples being taken in each case. The average count after four minutes of immersion was approximately the same as the average count for the three longer periods. The average count after two minutes was less than 130,000, the three, four, and five-minute samples varying from 150,000 to 300,000 with an average of 180,000.

Textile. Undershirts of viscose rayon were selected for the experiments since they were inexpensive and of simple design. The size was 42, average weight 2.6 ounces, and area 762 square inches. It was realized that, although viscose rayon is the most prevalent type used, results obtained with viscose might not be indicative of possible results with the other types, nor might the results with viscose rayon be indicative of possible results obtained in laundering tests with various silk fabrics. A teacher of textile chemistry suggested that comparative tests be made on the different varieties of rayon and silk for water and dirt absorption, retention of bacteria, ease of cleaning, and so on. It was felt that the variation of results, obtained in the experiments reported later in this paper, would have covered any small differences which might have been found between the types of fabric. More exact quantitative methods would be needed to show such differences in the percentage removal of bacteria from various textile surfaces.

Garment Sterilization. Since the plan was to inoculate these shirts with *E. coli,* it was felt that before inoculation, each garment should be rendered as sterile as possible. Two methods were used. One consisted of washing the shirt and ironing from wet to dry state and then storing immediately in a covered sterile glass casserole which had been baked in an electric oven at 450°F. for one hour. The other consisted of placing the shirt, which had been washed and dried, in the covered casserole and baking it in an electric oven at 225°F. for one hour. To determine whether either process produced complete sterilization, the shirt was immersed in two liters of sterile water, agitated by hand, squeezed, lifted up and down in the water for four minutes, and then wrung out, and a sample taken of the water. The first method, that of ironing the shirt, gave a bacterial count of slightly less than 200 per square inch, nine tests averaging 179 per square inch. The second method, baking the shirt, gave an average count of 225 per square inch, four tests being made. Neither showed decided superiority over the other as far as the final count was concerned, but the baking method, being more easily carried out, was used to the greater extent. Neither method indicated truly sterile conditions, although it was felt that the

baked shirt did represent a fairly sterile condition. However, the value of approximately 200 bacteria per square inch might be accepted as a starting condition.

Winegar (2) reported that the normal count of freshly laundered (commercially) cotton undershirts was about 1000 per square inch. This higher count may be due to the nature of the ribbed fabric used.

Normal Population. For comparison with these so-called sterilization methods, tests were made to determine the normal count of a surface exposed to the air of the laboratory room for 10 to 12 hours. The garments were left on a work bench over night. In the morning they were immersed in two liters of sterile water and agitated for four minutes by hand, samples being taken of the water to obtain an approximate count. Table 1 shows the results of 16 tests, the counts varying between 100 and 600 per square inch and averaging 219.

The data in Table 1, analyzed by the frequency of the count, between 100 and 200, 200 and 300, and so on, show that in 10 of the 16 experiments the population per square inch ranged between 100 and 200. Of the remaining six experiments, three show counts between 200 and 300 and the other three are somewhat higher. If only the lowest 13 values were used, the new average would be 165 per square inch, which may be more nearly the true population.

These values are similar to the result of a control experiment for one of the series, which is described later. This experiment consisted of washing and indoor drying four non-inoculated shirts, and resulted in an average count of 160 per square inch. Since the treatment of the shirts varied in each case, it is thought this value might better be termed the average count obtained by the method of sampling, rather than the normal population of a garment.

Table 1. Normal Population of Garments Exposed to Air

No. Exp.	No. bacteria	Pop. per sq. inch	No. Exp.	No. bacteria	Pop. per sq. inch
24a	114000	150	43a	207240	270
24b	193000	253	43b	79960	105
			43c	115280	151
26a	157000	206	43d	86800	115
26b	115000	151			
			44a	112430	161
28a	447160	586	44b	104400	137
28b	259160	340	44c	328320	430
28c	116170	152	44d	114400	150
28d	112700	148			
			Average	166400	219

Possible Errors. There are a number of possible errors in the methods employed. One is made in assuming that the bacteria obtained in sampling two liters of water in which a garment had been washed came entirely from the inoculated cloth. Some of the bacteria which developed colonies on the incubated plate may have come from the hands of the operator or from the air. In a few tests made on water in which the hands of the operator were washed a rather high count was obtained, between 1000 and 2000 per square inch, the area of the hands being roughly computed as 120 square inches.

As stated previously, there may have been antagonistic action between the types of bacteria, and the use of Gentian violet may have inhibited growth of *E. coli*. In addition every count was made from a diluted sample and the condition was not always the best to give satisfactory counts. In most cases the results of two or more dilutions were averaged for the final result.

It is unwise for the reader to make certain conclusions. First, he may think that a count of 150, being less than a count of 250 per square inch, means that there were fewer bacteria in the former case than the latter. The author assumes that in analysis of these bacterial counts differences less than 1000 are of little or no consequence. Hence, the difference between 200 and 300 is not significant. The reader may also infer that final counts in experiments with inoculated garments were only *E. coli*. No selective counting was done and those final counts are the total number of bacteria on the plate, corrected first to the total number in the water and in the second case per square inch of the surface of the cloth used.

The time of sampling often influences bacterial counts and hence, differences in time may have introduced errors. For instance, when four shirts were sampled after drying, the first 10 cc. sample in its test tube stood at room temperature for at least 10 minutes longer than the fourth sample. When delays occurred, this period of time was longer than 10 minutes. It is then reasonable to expect that the count for the first sample might always be greater than that for the fourth. This source of error probably is not important, for there was little or no food present in the samples to support multiplication except in the first sample which contained some of the original broth.

Series II, Washing

This series was designed to determine the number and percentage of bacteria removed by the mechanical agitation of washing.

Method. The method employed was to wash an inoculated shirt in four or five vessels of cool sterile water for four minutes in each case. In three experiments, No. 16, No. 18, and No. 41, the first vessel contained a 0.25 per cent soap in water solution, White King soap powder

being used. In all other experiments listed in Tables 2 and 3, the first vessel contained clear water, as did all the other vessels. After the garment was wrung out of the first vessel and dropped into the second, an assistant removed 10 cc. of water from the first vessel with a sterile pipette and ran it into a sterile test tube. All other vessels were immediately sampled after the garment was wrung out, and the five test tubes were taken to the bacteriology laboratory for dilution, plating, and incubation. Since a sample of the original culture with which the garment had been inoculated had also been taken, the final counts afforded an approximate number of bacteria in each vessel, and quick computations gave the percentage of the original number in each vessel.

Results. Table 2 gives the estimated number and Table 3 the computed percentage. None of these values should be accepted as accurate counts but only as approximate values. That is, the final averages of Table 3 should be interpreted to mean 30-35 per cent in the first vessel, one to five in the second, one to two in the third, and generally less than one per cent in the fourth and fifth waters.

All the experiments listed in Tables 2 and 3 were made on rayon shirts. Only one test was made with a piece of closely woven cotton material with the following percentage removal: 41.5, 4.4, 1.8, 0.2, and 0.2. These results except for the first figure are duplicates of those made with rayon shirts.

E. coli was used in all of this series except experiment No. 62. *Staphylococcus aureus* was used in No. 62 for contrast, the same process being employed. Because of the distinctive yellow color of the *aureus* colonies, those of the original number remaining after each washing were quite evident. It is realized that there are organisms in the air of the same color as the *aureus* type. Percentage removals in No. 62 are very close to the averages listed at the bottom of Table 3.

In contrast with these removal figures are those obtained by Winegar (2) for worn cotton undershirts. Her percentage removal figures for 10 successive baths of sterile water are: 1-30.7; 2-23.4; 3-14.9; 4-10.3; 5-7.3; 6-5.0; 7-2.6; 8-1.1; 9-0.6; 10-0.2. Although her method of computation is different, she reports similar figures to the author's for the removal in the first water. Baker (14) reports 25-40 per cent of the bacteria present removed by the first water in which a garment is washed, and Latzke's similar figures (3) vary between 13 and 28 per cent.

From the comparison of these various figures, one can only say that washing either through a cool suds bath and two cool rinses, the usual stages of home laundering, or through three or more clear waters does not remove all the bacteria on a garment. The first water removes the largest percentage. Washing may remove from 20 to 50 per cent, and other phases of the laundering process may remove the remainder.

Table 2. Removal of Bacteria in Successive Washings
(In millions)

No. Exp.	No. bacteria placed on shirt	Number bacteria in waters					Total
		(1)	(2)	(3)	(4)	(5)	
16	31,125	7,947*	479	460	136	.....	9,022
18	7,762	1,720*	145	41	1	.....	1,907
41	24,624	3,228*	293	236	.....	.....	28,381
53	50,750	19,749	2,229	391	189	66	22,624
55	38,000	20,160	549	478	293	117	21,597
61	70,000	30,000	3,000	1,000	130	115	34,245
62	75,000	25,430	2,910	1,205	250	90	29,885
63	23,500	8,226	946	539	391	60	10,162
64	28,500	4,907	1,583	508	92	37	7,127

* Suds Used.

Table 3. **Percentage of Bacteria Removed in Successive Washings**

No. Exp.	Percentage of bacteria in waters					Total
	(1)	(2)	(3)	(4)	(5)	
16	25.5*	1.54	1.48	.44	....	29.0
18	22.2*	1.87	.53	....	....	24.6
41	33.7*	4.40	.40	.30	....	38.8
53	38.9	4.40	.80	.37	.13	44.6
55	53.0	1.50	1.30	.80	.30	56.9
61	42.8	4.20	1.40	.45	.40	49.2
62	32.0	4.00	1.60	.33	.12	38.0
63	35.0	4.00	2.20	1.60	.25	43.0
64	17.2	5.50	1.80	.32	.12	24.9
Average	33.4	3.49	1.28	.51	.15	38.8

* Suds Used.

Series III, Drying

This series was designed to test the efficacy of indoor and outdoor drying on inoculated shirts. It was felt that the best time to test the effect of drying was after a shirt had been washed in the ordinary way and then dried. Therefore, sampling followed washing and complete drying, either indoors in the laboratory for about four hours, or out of doors in the sunshine for two to three hours between nine o'clock and twelve noon during May, June, and September, 1931.

Method. First, four garments were baked in four covered glass casseroles at 225°F. for one hour, between four and five o'clock. They were allowed to cool overnight in the oven, and at eight o'clock 50 cc. of culture were poured over each shirt. After a period of five to ten minutes to allow the garment to absorb the broth, the four shirts were washed together by hand for about four minutes with squeezing and constant agitation in about eight liters of cool tap water containing 30 grams of soap. They were then wrung out separately and dropped into a second tub of cool rinse water, agitated for four minutes, rinsed a second time, and hung up to dry.

After drying, the shirts were dropped into separate vessels of sterile water, agitated for four minutes, and wrung out. A sample of water was immediately withdrawn by the assisting student, and within an hour's time all samples were diluted, plated, and placed in the incubating oven. Forty-eight hours later a count was made. A one cc. sample of the original culture had also been diluted, plated, and incubated to estimate the approximate number of millions of bacteria placed on the garment.

The final count divided by the original number gives the percentage of the original removed by the sampling, and this is reported in the tables, as are the actual counts and the population per square inch.

The count of the bacteria in water in which the garment had been sampled was at first considered the number of bacteria remaining on the garment after washing and drying. Later, it was felt that, judging by the results of Series 2, not all the bacteria on a surface were removed by agitation in one water nor, in fact, by three or more waters. The final count then must be accepted as an approximate figure only, an unknown fraction of the true number of bacteria that have survived the test process. Nevertheless, the removal must be nearly complete because extremely small percentages were found removable in the sampling.

Table 4. Effectiveness of Washing and Indoor Drying

No. Exp.	No. bacteria placed on shirt (in millions)	Bacterial count on sampling after drying		
		Total number	Percentage original amount	Pop. per sq. inch
17	448	1,988,000	.4440	2610
18	7,762	1,117,600	.0144	1460
20a	19,137	1,404,000	.0074	1842
20b	11,062	2,395,000	.0216	3140
20c	16,175	1,780,000	.0110	2340
20d	2,275	5,001,700	.2200	6560
27a	2,332	321,100	.0138	421
27b	5,550	168,000	.0030	220
27c	75,300	223,300	.0003	306
27d	3,300	105,300	.0032	138
33a	10,250	156,800	.0015	206
33b	22,000	142,000	.0006	186
33c	10,150	168,500	.0016	221
33d	2,600	159,000	.0061	209
34a	56,750	439,400	.0008	576
34b	45,250	5,222,800	.0116	6850
34c	72,000	7,716,900	.0107	10100
34d	562	238,500	.0424	312
36a	84,500	1,638,000	.0019	2150
36b	88,250	4,240,300	.0048	5560
36c	65,000	1,026,600	.0016	1344
36d	50,850	603,000	.0012	791
Averages		1,648,000	.0374	2160

Results: Indoor Drying. Table 4 presents the results obtained after indoor drying experiments. The final counts vary between 100 and 10,000 per square inch and average 2160 bacteria per square inch. According to the percentage column, the same counts vary between .0003 and .44, averaging .037 or approximately .04 per cent. Hence, one would assume that 99.96 per cent of the bacteria placed on the garment were removed by the combined action of washing and indoor drying.

For purposes of comparison, four non-inoculated shirts were washed, rinsed, dried indoors, and then sampled. The average count was 122,000 or 160 per square inch. This value is of the same order as the average shown in Table 1. The non-inoculated shirt, after treatment with an average population of 160 per square inch, has a decidedly lower value than the inoculated shirt after the same treatment with an average population of 2160. The ratio is one to 14.

It will be noted that the counts listed in Table 4 show more variation than those of previous tables. Of the percentage figures, two are in the tenths of one per cent, seven in the hundredths, ten in the thousandths, and two in the ten-thousandths. In the fifth column, half of the items are above 1000 and half less than 1000. Since the number of bacteria placed on the shirt could not be controlled, some variation in the final results was to be expected. The shirts were dried in a laboratory used by four investigators, some variation might therefore be expected from conditions in the room.

If the count resulting from the method of sampling, Series I, Materials, were subtracted from the average count after indoor drying, the difference, approximately 1950 bacteria per square inch, might be considered the number of bacteria per unit area that survived both washing and drying. All bacteria reported in Table 4 were not *E. coli*, nor were nine-tenths of them of this type. The longer drying period in a moist atmosphere is most likely the cause of the higher counts obtained.

Results: Outdoor Drying. The method employed for outdoor drying tests was the same as for indoor experiments. The garments were sampled immediately after being brought into the laboratory. Table 5 shows the results in actual counts (averages of several dilutions, corrected to total in vessel), as percentages of the original amount, and as the count per square inch. The actual counts vary from 11,000 to 332,000, averaging approximately 119,000. The percentage variation is from .0001 to .013; the average, .0037 or approximately .004. The values in the column showing the number per square inch of cloth vary from 15 to 436, averaging 156.

From the average percentage .004, one would judge that 99.996 per cent were removed. The highest percentage figure in the column is .013, with a 99.987 per cent removal. These values indicate that outdoor

drying is slightly better than indoor drying. Either is very satisfactory, except perhaps in cases of spore-bearing bacteria, which are extremely hardy and can only be destroyed by boiling or still higher temperatures applied for 10 to 20 minutes.

Table 5. Effectiveness of Washing and Outdoor Drying

No. Exp.	No. bacteria placed on shirt (in millions)	Bacterial count on sampling after drying		
		Total number	Percentage original amount	Pop. per sq. inch
23b	6,050	159,300	.00264	209
23c	7,150	36,200	.00050	47
23d	11,950	17,800	.00015	23
30a	798	61,500	.00772	81
30b	413	46,240	.00020	60
30c	313	39,640	.01270	52
30d	195	26,880	.01380	35
31a	6,420	222,500	.00350	292
31b	6,300	36,080	.00057	47
31c	8,575	11,310	.00013	15
31d	6,175	70,520	.00114	92
37a	56,250	182,000	.00032	238
37b	64,750	273,600	.00042	358
37c	49,500	272,800	.00055	358
37d	82,750	332,500	.00040	436
Average	390	119,260	.00372	156

For purposes of comparison four shirts, non-inoculated, were washed, rinsed, and dried out of doors, and then sampled as in the experiments listed in Table 5. The average count was 113,700 or 149 per square inch. This value is approximately that of the average of Table 1, and also that of the check experiment of the indoor drying series. It is also the same as the average population per square inch of Table 5. One might assume from this check experiment that the bacteria applied to the garments for outdoor drying tests were entirely eliminated by the bright sunlight and that the counts of 149 or 156 per square inch represent again the count obtained by the method of sampling.

Analyzing Table 5 from a statistical viewpoint, the variation is much less than that found in Table 4. In five cases the population per square inch is over 250, and in ten, less than 250. Of the percentage figures,

two are in the hundredths of one per cent; four, in the thousandths; nine, in the ten-thousandths. The five highest counts in columns three and five are really not high counts, judging by their respective percentage values.

Series IV, Ironing

A few tests were made to evaluate the actual effect of ironing and to check literature data. Four pieces of viscose rayon, each about 100 square inches in area, baked in glass casseroles as in the other experiments, were inoculated with 10 cc. of *E. coli*. These were then ironed from the wet state until dry and each immediately dropped into two liters of sterile water. The vessels were covered and shaken for four minutes. The cloth was removed, not by the hands of the operator which might have introduced bacteria, but with a pair of metal tongs that had been held in a stream of hot water to obtain at least partial sterilization. Samples were taken of the four lots of water, and a count made 48 hours later showed (1) no colonies, (2) no colonies, (3) one colony, and (4) one colony. This indicates that ironing, considered as a single factor, is effective in practically destroying all bacteria placed on the cloth.

Summarizing data on germicidal temperatures, one finds that the range, 140-160°F. is destructive to many pathogenic bacteria, and 205-212°F. eliminates practically all non-spore-bearing types. Each spore-bearing type has some critical thermal death point, these temperatures being higher than ordinary boiling temperatures. The textiles used in garments have varied characteristics, particularly with respect to temperature. Cotton and linen may be boiled and ironed with a hot iron 400-450°F. Silk, rayon, and wool cannot be boiled without serious damage to the fibers. The respective scorching temperatures in degrees Fahrenheit, according to Gilmore (15), are:

Textile	Time of Contact in Seconds		
	1	2	3
Cotton	510	487	442
Viscose	463	.....	375
Linen	447	425	403
Silk	447	425	403
Wool	397	375	350

From this table of scorching temperatures one sees that rayon may be ironed with a warm iron. Thorough ironing should produce temporarily sterile conditions, and the lower temperature range should not damage the fabric.

HYGIENE OF LAUNDERING

Hygiene of Laundering. One of the questions arising during the course of this project was whether or not a person might reinfect himself by wearing a silk or rayon undergarment insufficiently sterilized by laundering. Actual determination of this fact seemed impossible with present equipment, but a search was made of medical literature to locate any favorable or unfavorable comment on the point in question. One physician commenting on this point said that, practically, there was not much danger of reinfection but that, scientifically, he would be interested to know whether bacteria would survive laundering. Another physician felt that reinfection from clothing was possible.

If laundering had little germicidal action, whether or not bacteria might be transferred from an infected garment to a non-infected garment, and cause infection in the wearer, is another question. Judging from the results of the drying tests, there is not much danger except perhaps in the case of spore-bearing bacteria or fungi.

Incidence of Ringworm. The problem of ringworm infection is a vital one today. Very high incidence of ringworm of the feet is reported in college circles (16), and Osborne and Hitchcock (17) make the statement that approximately 50 per cent of the adult public is so affected. Legge at the Univerisity of California is investigating the subject of ringworm infection, treatment, and prevention.

Since this skin condition is caused by a fungus growth, the spores of which are destroyed at a temperature of 248°F. (18), it seems possible that present laundering methods for stockings are not sufficiently thorough to eliminate all spores. In contrast, Legge says that water at a temperature from 176-212°F. will destroy the spores. Woolen and silk stockings, which are washed in warm suds, rinsed in warm water, dried and not ironed, might easily retain the spores of the growth transmitted to the cloth by the sweat of the feet. Legge, in a personal communication to the author, says, "One of the reasons for so much reinfection is that woolen socks are never boiled due to their shrinking." Search is being made for a suitable fungicide to destroy the spores. Gasoline will not harm silk, rayon, or wool and is a known fungicide, but how effective it is in this case is not known. Sodium hypochlorite and sodium thiosulfate solutions are used in foot baths to limit the spread of this skin disease in gymnasiums and swimming pool corridors with evident success. The former chemical is a bleach and should not be used with silk, rayon, or wool. Whether the thiosulfate is harmful to silk, rayon, and wool is not known. Only one comment was found in a medical journal on methods of sterilizing silk underwear. This recommended immersion in a solution of one part in 1000 of corrosive mercuric chloride, which would "probably not damage the silk fiber." The best and most efficient

solution for hardy pathogenic and spore-bearing types of bacteria has not been determined, and is a reasonable problem for future investigation.

Bacteria on Worn Garments. Winegar (2) reported finding the following bacteria on worn athletic undershirts: *Micrococcus aureus, Micrococcus albus, Streptococci, Sarcina,* and *E. coli.* Tests made after a single wearing of the shirts gave counts of about 400,000 per square inch. Counts made after two, three, and six periods of wear (30 minutes each) varied between six and nine million per square inch. Similar tests made by the author on 19 rayon undershirts, each worn for two days by four women doing sedentary work, showed the following types present: *Staphylococcus albus, Staphylococcus citreus, B. subtilis,* and molds. Counts varied between 300 and 20,000 per square inch. This variation was considerable and it eliminated the possibility of using worn garments for further tests. The high population of worn garments in both cases confirmed the idea that more care need be taken, particularly in the case of infectious diseases. It is reasonable to say that undergarments need be changed often from a sanitary standpoint as well as an aesthetic one.

Bacteria on Skin. If infected garments are worn, the next point in question is, what would happen if bacteria were applied to the skin. They might enter at any unprotected cut or wound, or if applied to a mucous membrane. Arnold and others (19) reported experiments indicating that the skin had power to destroy bacteria. Norton and Novy (20), duplicating Arnold's tests with *Bacillus prodigiosus,* found that bacteria applied to the skin diminish in numbers very rapidly, but concluded that this was due not to some inherent power of the skin, but to the absence of moisture. Marked disappearance of organisms was coincident with dryness of the surface and persistence was noted on moist areas.

CONCLUSIONS

Certain factors of the laundering process as soap, time, and temperature might be analyzed for their individual characteristics in garment sterilization.

Water. Water, of itself, is not germicidal; even distilled water permits bacterial life; water at a high temperature may be germicidal, but the effect is due to temperature; when soil and bacteria are removed from a surface in washing, their removal is due to the mechanical action.

Soap. Ordinary laundry soap concentrations are not germicidal; high concentrations (five to ten per cent solutions) of certain soaps have specific action against certain strains of bacteria; the cleaning action of soap is due to the physical removal of dirt particles or bacteria from a surface by emulsification.

Additional Laundering Reagents. The use of detergents containing oxygen are thought to produce some bactericidal effect; bleaches containing chlorine, included in one of the rinses, should aid materially in producing sterile conditions, but high concentrations are needed to destroy all types of bacteria; high concentrations of such bleaches are damaging to colored fabrics and to silk and wool; bluing has no bactericidal action; germicidal or fungicidal solutions might well be used in the laundering process in cases of infectious diseases.

Time. From the experiments described, longer periods of agitation are more effective than shorter ones in the removal of bacteria; in any bactericidal process action is not instantaneous, hence time is to be considered as important as temperature.

Temperature. Temperatures under 95°F. are not germicidal; temperatures over 104°F. are somewhat germicidal; those over 140°F., particularly moist heat, are germicidal for most pathogenic bacteria; much higher temperatures maintained for some time are needed to eliminate some of the spore-bearing bacteria and fungi.

Textiles. Cotton and linen are readily cleaned of soil and bacteria by the use of suds and rinses at high temperatures; silk, rayon, and wool may be cleaned by cool suds and rinses, but are not rendered sterile by the appropriate laundering process; hence, the nature of the textile needs be considered in a study of the bactericidal efficiency of a laundering process.

General conclusions for the four series of experiments involve a number of the factors mentioned above. Since the experiments covered four distinct subjects, new interrelations may be seen by restatement, particularly in the light of the above six factors.

First, all surfaces exposed to the air show a count of approximately 200 bacteria per square inch and although they may enter during the process of sampling this value at least gives a basal condition.

Second, washing an article in suds and two rinses, or through three waters, eliminates from 20 to 50 per cent of the original number of bacteria placed on the garment. Other investigators also report similar percentages, the highest amount being found in the first water.

Third, drying removes approximately 99 per cent of the bacteria placed on the garment, this per cent including the amount removed by washing. Results after indoor drying average over 2000 bacteria per square inch, and after outdoor drying less than 200 per square inch.

Fourth, ironing alone removes approximately 100 per cent of the bacteria placed on a garment. Ironing non-inoculated surfaces removes bacteria but only temporarily. Temperatures of 300° to 400°F. are sufficiently

germicidal for the non-spore-bearing bacteria and for some of the spore-bearing types, if the time factor is great enough.

In summary, the bactericidal efficiency of the various stages of the laundering process is: washing 20-50 per cent; washing and drying 99 per cent; and ironing 100 per cent.

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